GIGAPHOTON

HIGH POWER LPP-EUV SOURCE WITH LONG COLLECTOR MIRROR LIFETIME FOR HIGH VOLUME SEMICONDUCTOR MANUFACTURING

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Agenda

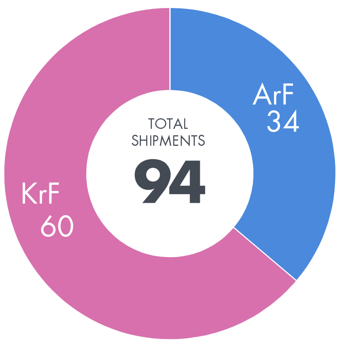
- Introduction
- HVM Ready System Performance Progress and Target
  - Power Scalability
  - Collector Mirror Life Extension
- Availability Improvement
- Summary

INTRODUCTION

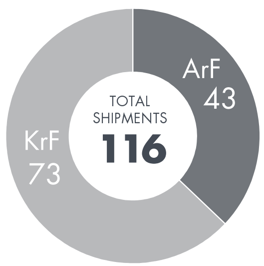
2016 Lithography Source Business Highlights

DUV Business

- In 2016, Gigaphoton achieved 60% share in DUV market
- Achieved 10,000 Kiloliter Ne Gas annual reduction
- Announced a new Green Innovation Roadmap with new environmentally friendly and economical technologies



2016



2015

EUV Business

- Began integration of Pilot system for scanner integration
- >100W average power with 5% CE on Pilot system
- Demonstrated 250W capabilities with 4% CE at 100KHz

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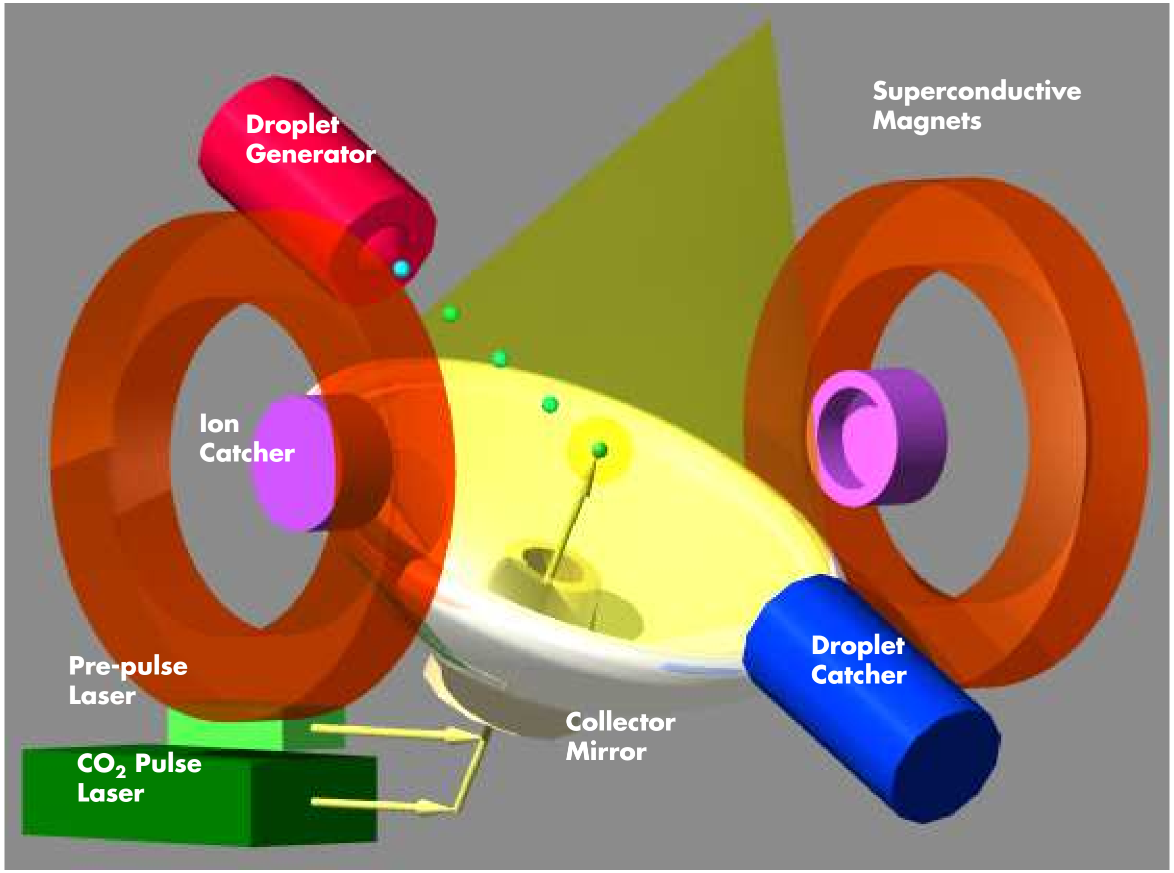
HVM READY PERFORMANCE PROGRESS AND TARGETS

Gigaphoton LPP Source Concept

1. High ionization rate and CE EUV tin (Sn) plasma generated by dual-wavelength shooting via CO_2 and pre-pulse solid-state lasers
2. Hybrid CO_2 laser system with short pulse high repetition rate oscillator and commercial cw-amplifiers
3. Tin debris mitigation with a super conductive magnetic field
4. Accurate shooting control with droplet and laser beam control
5. Highly efficient out-of-band light reduction with grating structured C1 mirror



Key Performance Status and its target

	2015	2016	**2017 Current**	**2018**
In-band power (Average Power)	87W (83W)	113W (111W)	**113W (91W)**	**250W**
Collector lifetime*1	No data	-10%/Bpls *3	**-0.4%/Bpls**	**-0.2%/Bpls**
Availability*2	15%	44%	**53%**	**> 80%**

Proto #2 **Pilot #1**

*1, Collector lifetime estimation has been started from 2017
*2, Max availability in 4 week operation.
*3, Main issue was capping layer performance.

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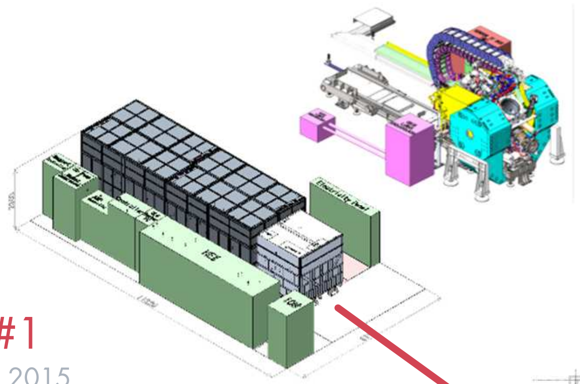
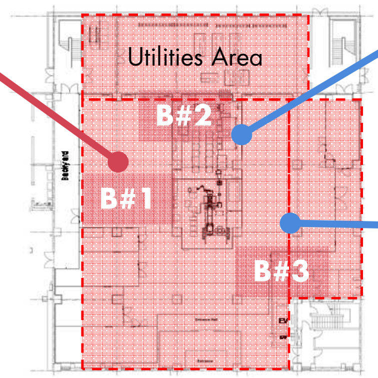
Current EUV Sources at Gigaphoton

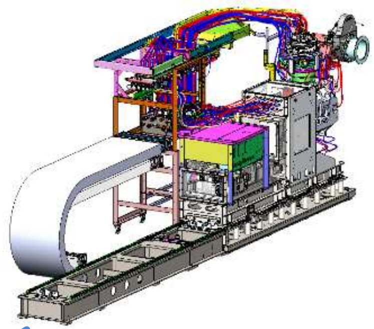


NEW **Pilot#1**

Operational since 2015

First pilot EUV system designed for ASML NXE integration and HVM operations

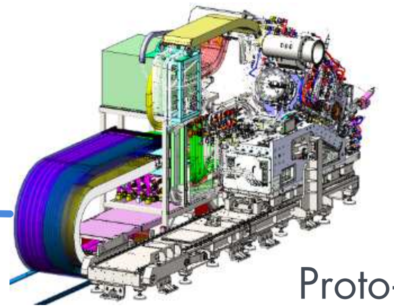




Proto#1

Operational since October 2012

Elemental technology research and proof of concept



Proto#2

Operational since November 2013

Key technology development for HVM

Target System Specification

		Proto#1 Proof of Concept	Proto#2 Key Technology	Pilot#1 HVM Ready
Target Performance	EUV Power	25W	>100W	**250W**
	CE	3%	> 4%	**> 5%**
	Pulse Rate	100kHz	100kHz	**100kHz**
	Output Angle	Horizontal	62°upper	**62°upper**
	Availability	~1 week	~1 week	**>80%**
Technology	Droplet Generator	20 - 25μm	< 20μm	**< 20μm**
	CO_2 Laser	5kW	20kW	**27kW**
	Pre-pulse Laser	picosecond	picosecond	**picosecond**
	Collector Mirror Lifetime	Used as development platform	10 days	**> 3 months**

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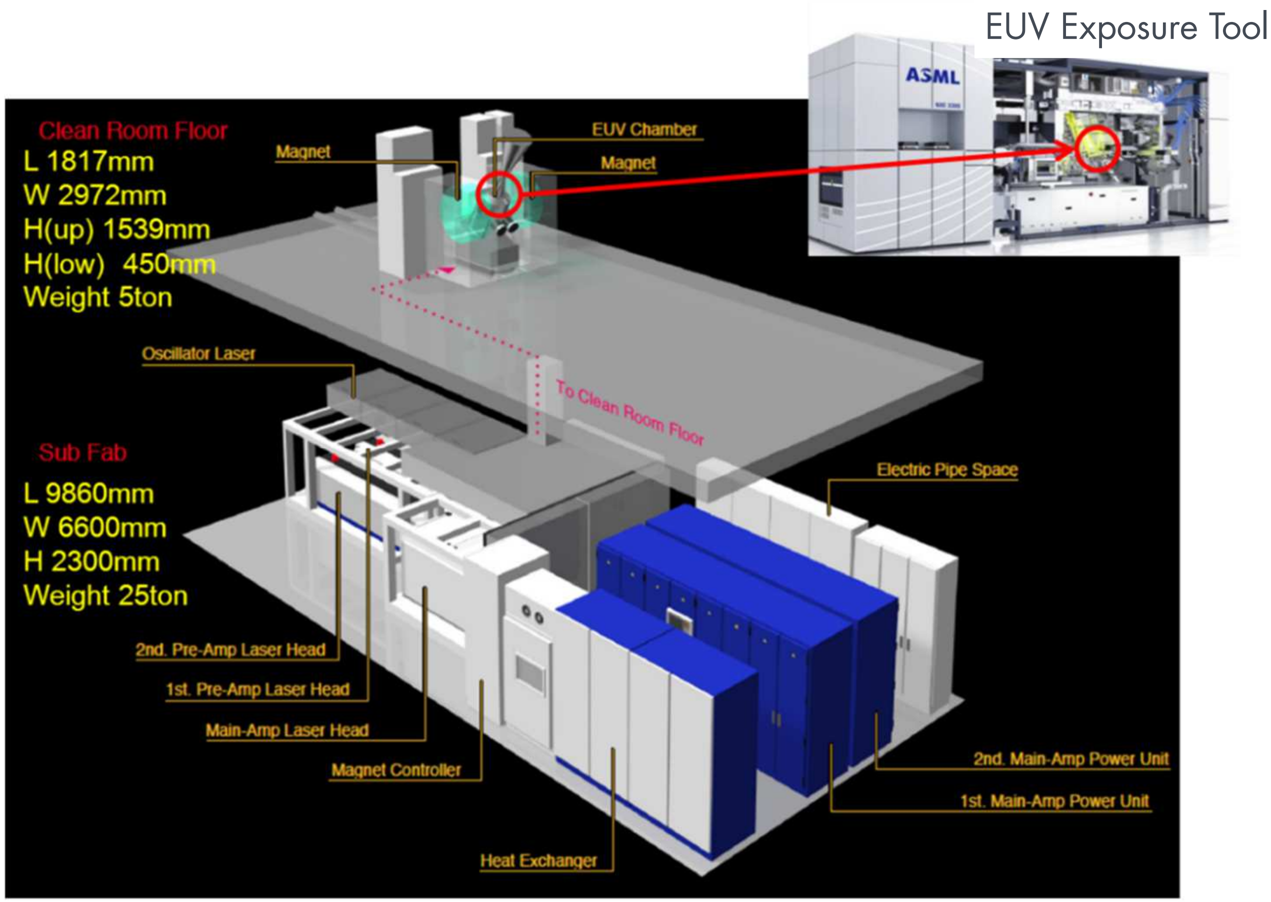
HVM READY
POWER SCALABILITY

Layout of 250W EUV Light Source Pilot #1

First HVM EUV Source

- 250W EUV source

Operational specification (Target)			HVM Source
Performance	EUV Power		> 250W
	CE		> 4.0 %
	Pulse rate		100kHz
	Availability		> 80 %
Technology	Droplet generator	Droplet size	< 20mm
	CO2 laser	Power	> 20kW
	Pre-pulse laser	Pulse duration	psec
	Debris mitigation	Magnet, Etching	> 15 days (>1500Mpls)



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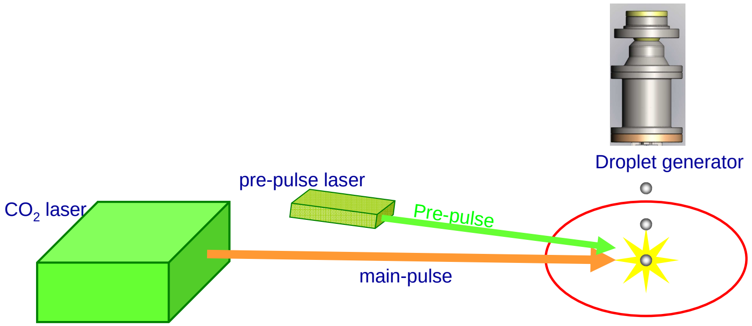
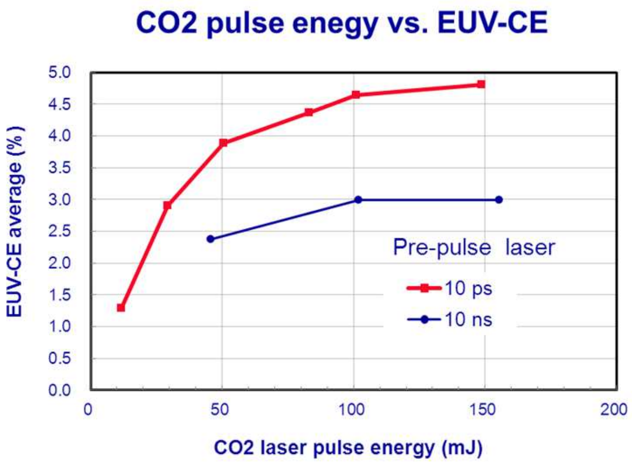
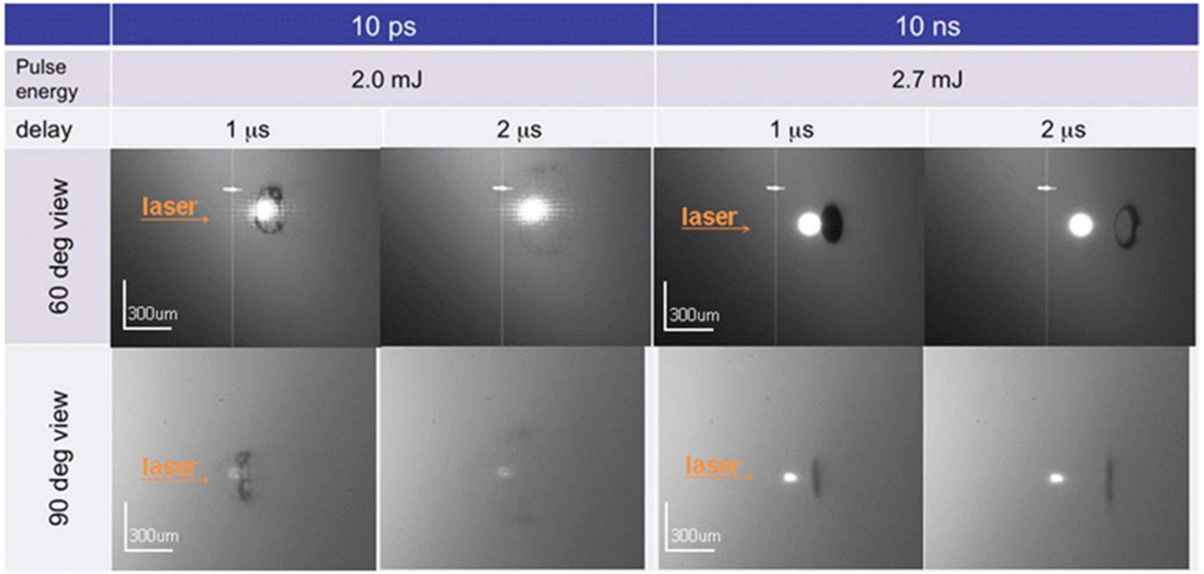
Pre-Pulse Technology





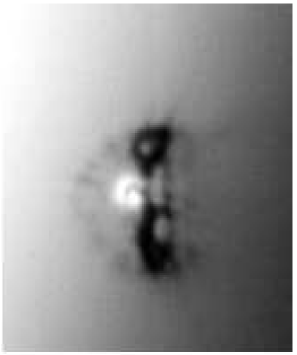
- The mist shape of a picosecond pre-pulse is different from that of a nanosecond
- Nano-cluster distribution could be a key factor for high CE



Pre-Pulse Technology

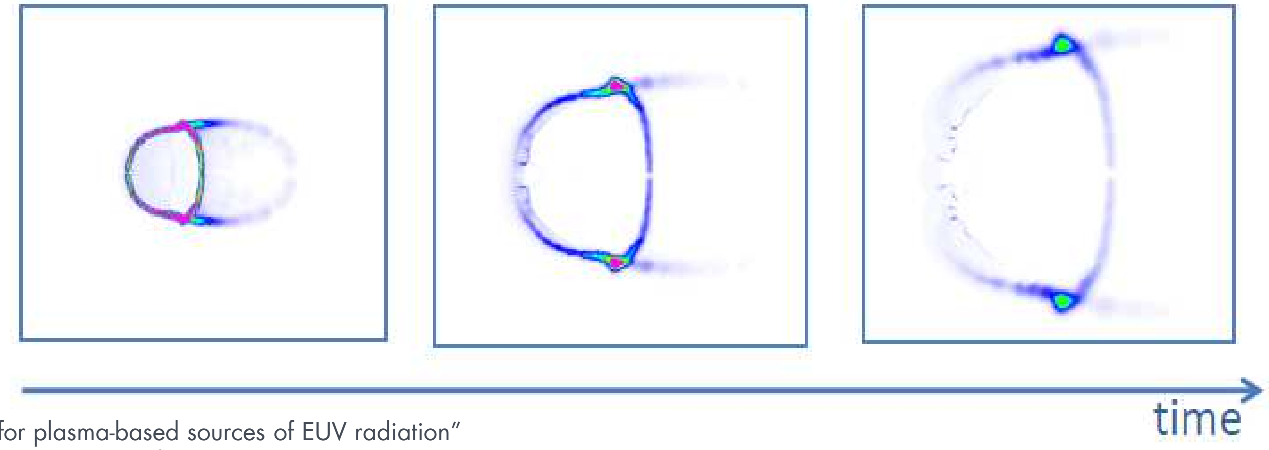
Modeling picosecond pre-pulses

~ 10 ps pre-pulse
"Dome like target"



H. Mizoguchi, Dublin (2013)

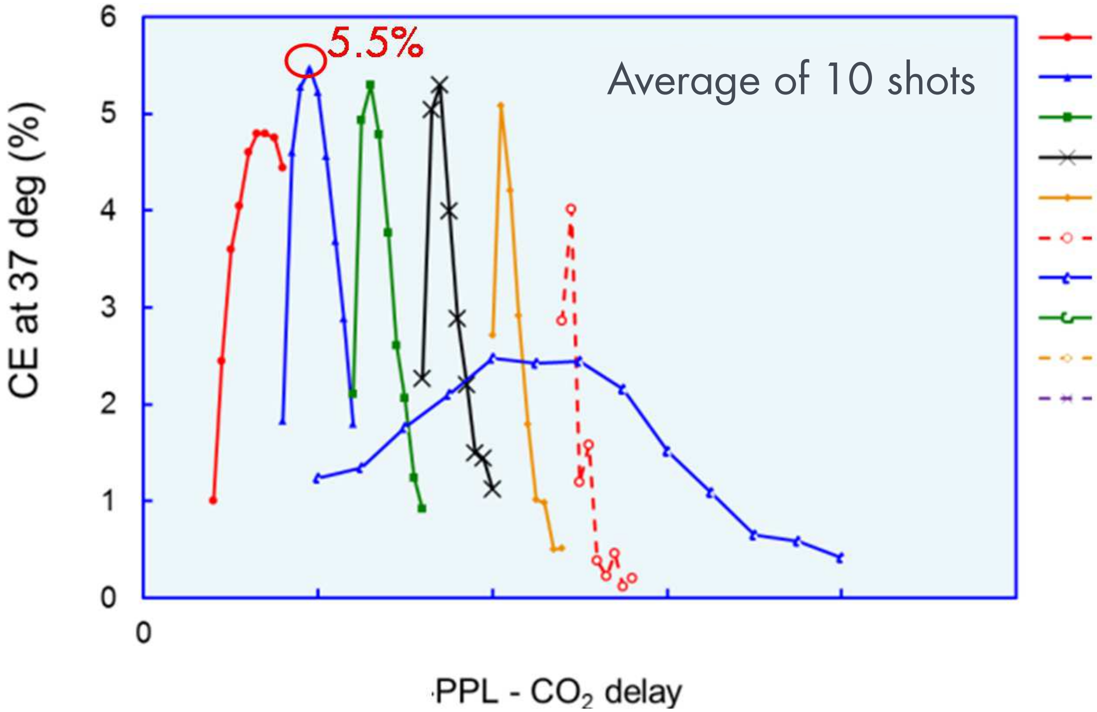
RALEF simulations
Evolution of Sn density profile for 10 ps pre-pulse

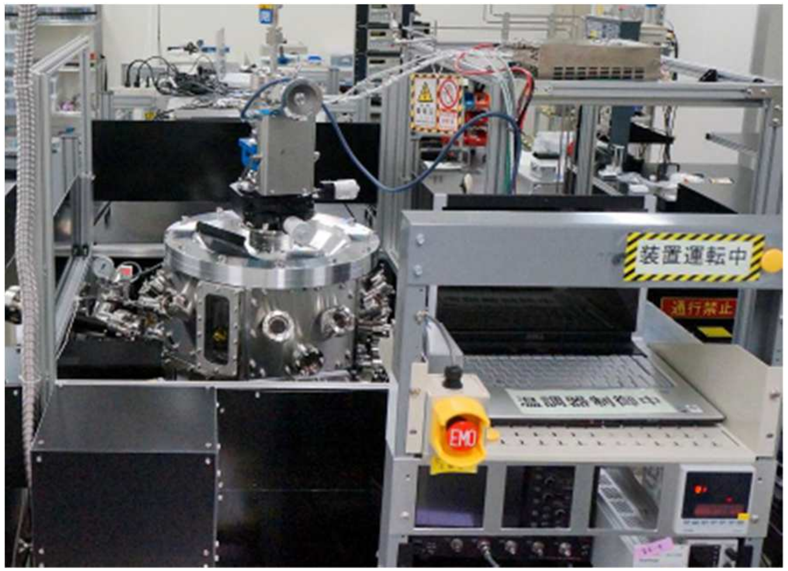


"Advances in computer simulation tools for plasma-based sources of EUV radiation"
V.V. Medvedev[1,2], V.G. Novikov[1,3], V.V. Ivanov[1,2], et.al.
[1] RnD-ISAN/EUV Labs, Moscow, Troitsk, Russia
[2] Institute for Spectroscopy RAS, Moscow, Troitsk, Russia
[3] KeldyshInstitute of Applied Mathematics RAS, Moscow, Russia

Pre-Pulse Technology

In an experiment device, we observed **5.5% CE** under optimized conditions. This was a **17% increase** from our old champion data (CE = 4.7%).





Experiment Device

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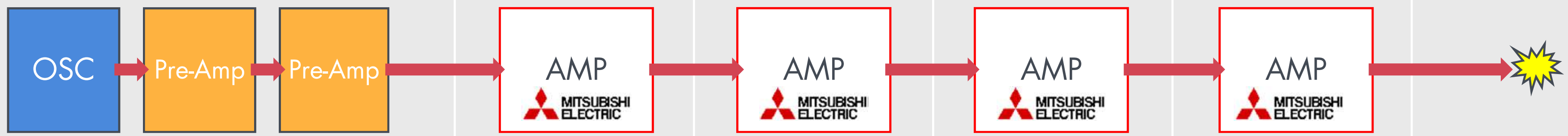
Pilot#1 – Driver Laser and PPL System



OSC		PA1	MA1	MA2	MA3	Plasma Point
For 250W EUV	100W	5kW	10kW	20kW	30kW	27kW

Basic Experiment in 2013

1st Amplifier installation in 2015

Amplifier system installation in 2016

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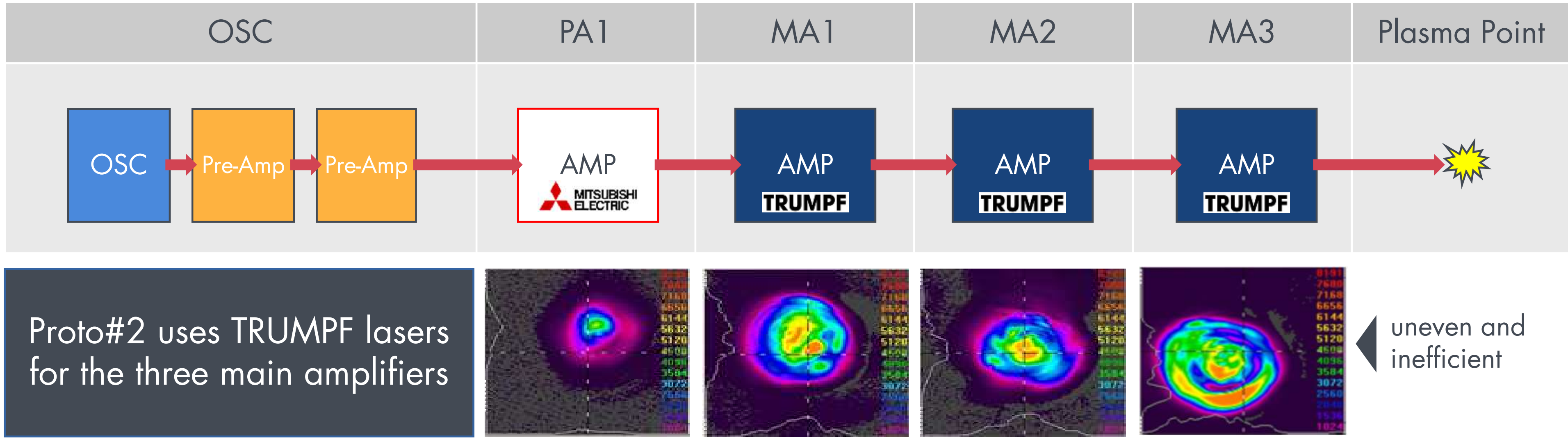
Pilot System Driver Laser and PPL System Improvements



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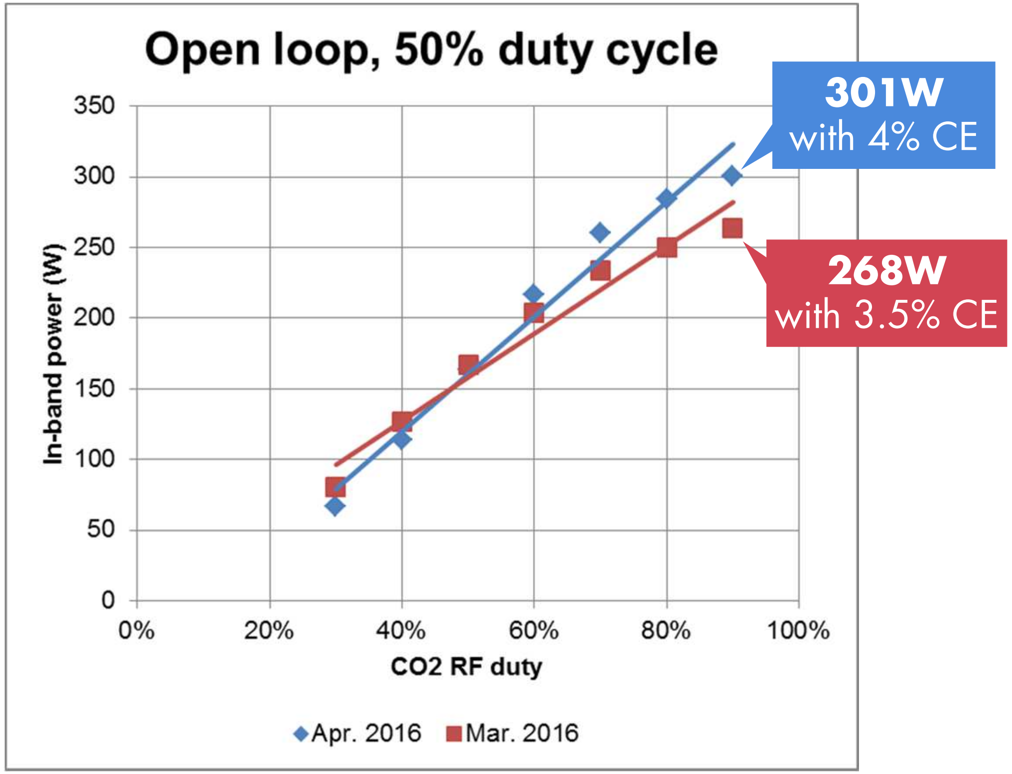
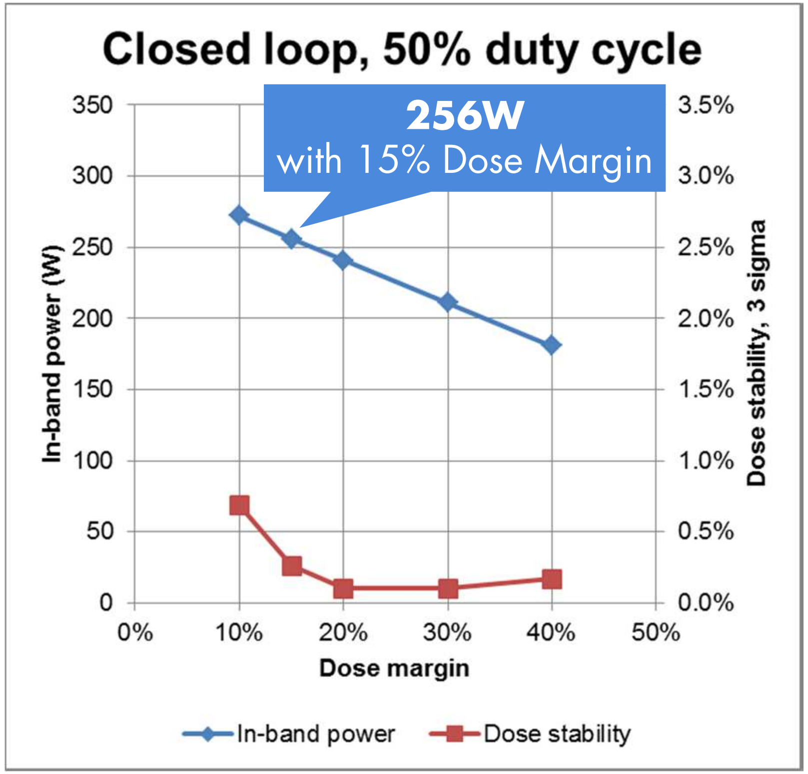
Latest LPP Source Systems Experiment Update

Proto#2: 250W with 4% CE at 100KHz





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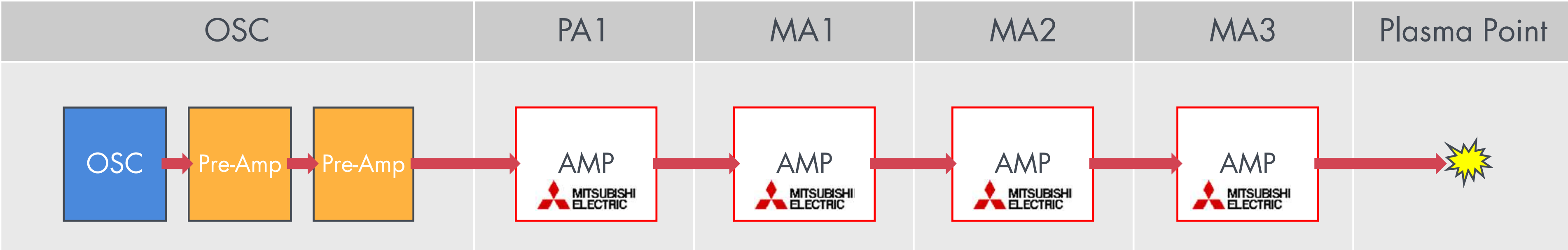
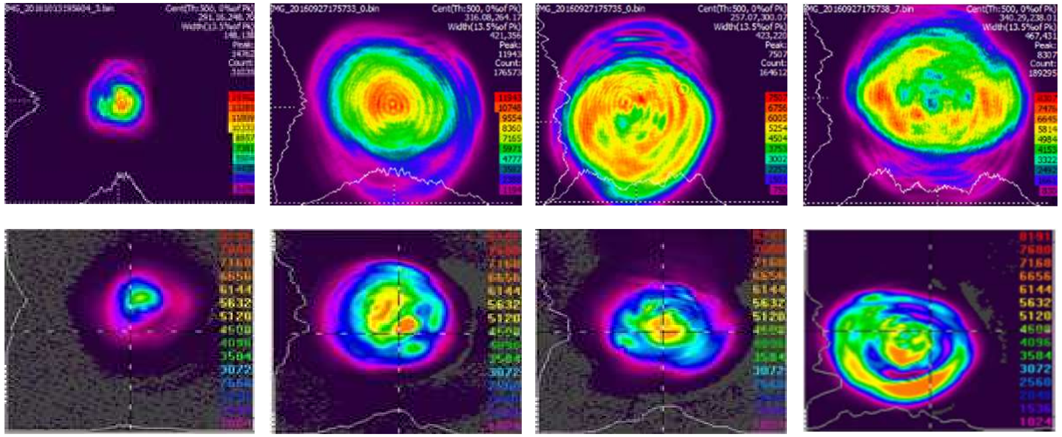
Pilot System Driver Laser and PPL System Improvements



Pilot#1 uses Mitsubishi lasers for all amplifiers

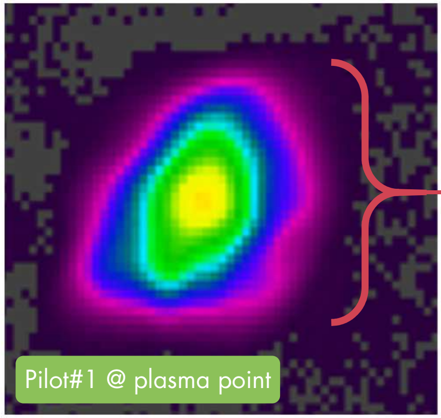
Proto#2 uses TRUMPF lasers for the three main amplifiers



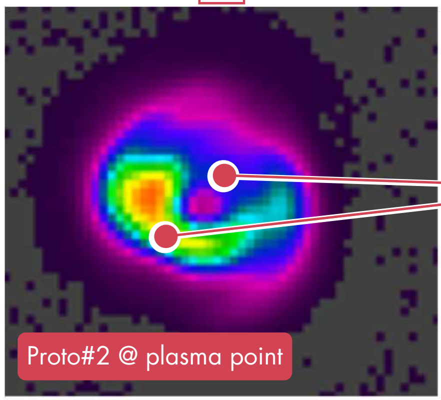
greatly improved uniformity

Pilot System Driver Laser and PPL System

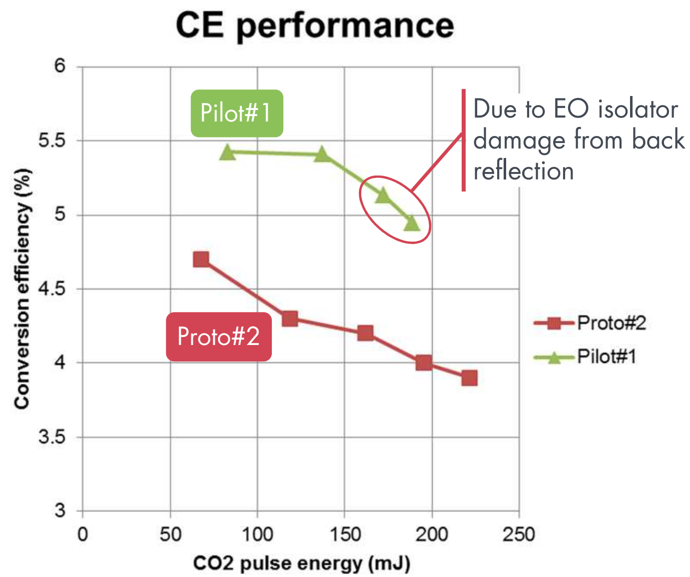
>5% CE was achieved due to the greatly improved CO_2 beam profile



Greatly improved evenness in beam profile allows for more uniform and efficient ionization of droplets – thus resulting in higher CE



Previous CO_2 beam profile was very uneven and hence less efficient by comparison



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High Power EUV Source for High NA EUV exposure tool

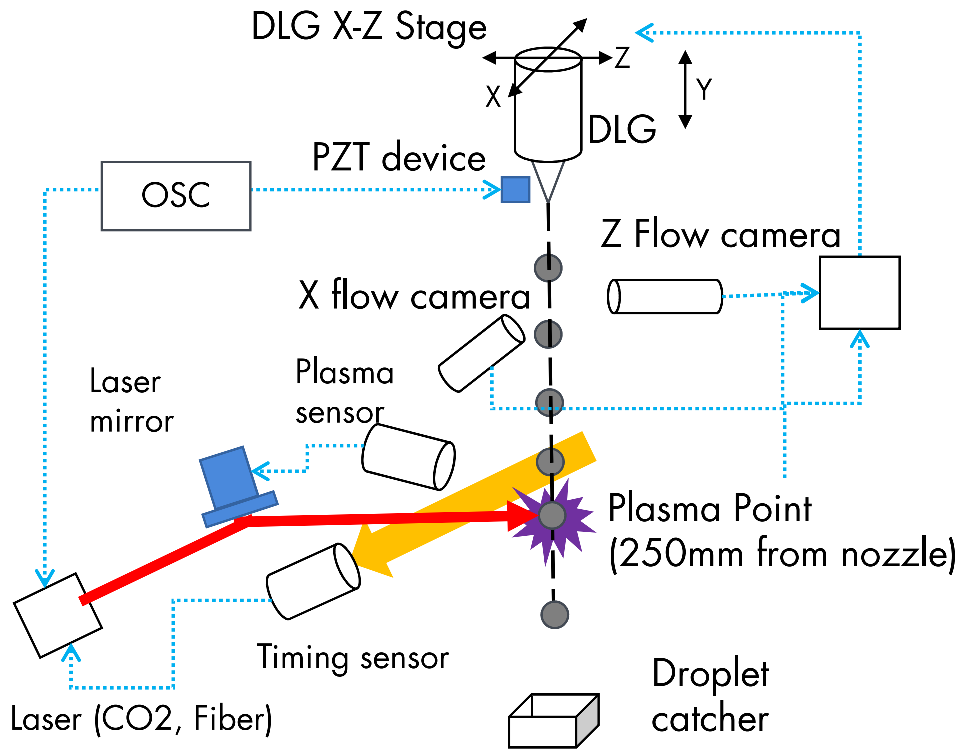
CO2 laser Energy [mJ]	CO2 laser ave. Power [kW]	2%	3%	4%	5%	6%	7%	8%
EUV ave.Power[W] @100kHz		Conversion Efficiency [%]						
15	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	5	19.1	28.7	38.2	47.8	57.3	66.9	76.4
100	10	46.4	69.6	92.8	[illegible]	139.2	162.4	185.6
150	15	73.7	110.6	147.4	[illegible]	221.1	258.0	294.8
200	20	101.0	[illegible]	202.0	[illegible]	303.0	353.5	404.0
250	25	128.3	192.5	256.6	**320.8**	384.9	449.1	513.2
300	30	155.6	233.4	[illegible]	389.0	466.8	544.6	622.4
350	35	182.9	274.4	365.8	457.3	548.7	640.2	731.6
400	40	210.2	315.3	420.4	525.5	630.6	735.7	840.8
450	45	237.5	356.3	475.0	593.8	712.5	831.3	950.0
500	50	264.8	397.2	529.6	662.0	794.4	926.8	1059.2
550	55	292.1	438.2	584.2	730.3	876.3	1022.4	1168.4
600	60	319.4	479.1	638.8	798.5	958.2	1117.9	1277.6
650	65	346.7	520.1	693.4	866.8	1040.1	1213.5	1386.8
700	70	374.0	561.0	748.0	935.0	1122.0	1309.0	1496.0
750	75	401.3	602.0	802.6	1003.3	1203.9	1404.6	1605.2
800	80	428.6	642.9	857.2	1071.5	1285.8	1500.1	1714.4
850	85	455.9	683.9	911.8	1139.8	1367.7	1595.7	1823.6
900	90	483.2	724.8	966.4	1208.0	1449.6	1691.2	1932.8
950	95	510.5	765.8	1021.0	1276.3	1531.5	1786.8	2042.0
1000	100	537.8	806.7	1075.6	1344.5	1613.4	1882.3	2151.2

Lithography	R(nm)*	NA	λ/n (nm)	Power (W)
KrF dry	102	0.85	248	40
ArF dry	73	0.93	193	45
F_2 dry	69	0.80	157	-
ArF immersion	50	1.35	134	90
EUV	14	0.33	13.5	>250
EUV (High NA)	7	0.6	13.5	>500

	HVM1	HVM2	HVM3
EUV Power	250W	300W	500W
Pulse Rate	100kHz	100kHz	100kHz
CE	4.5%	5%	5%
CO_2 Laser Power	25kW	25kW	40kW

Pilot System Droplet Generator

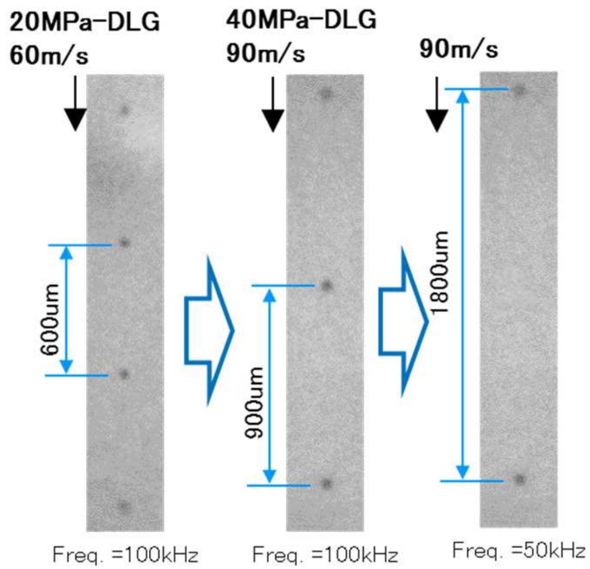
LPP EUV Source Shooting Control System



Pilot System Droplet Generator Technology Transfer

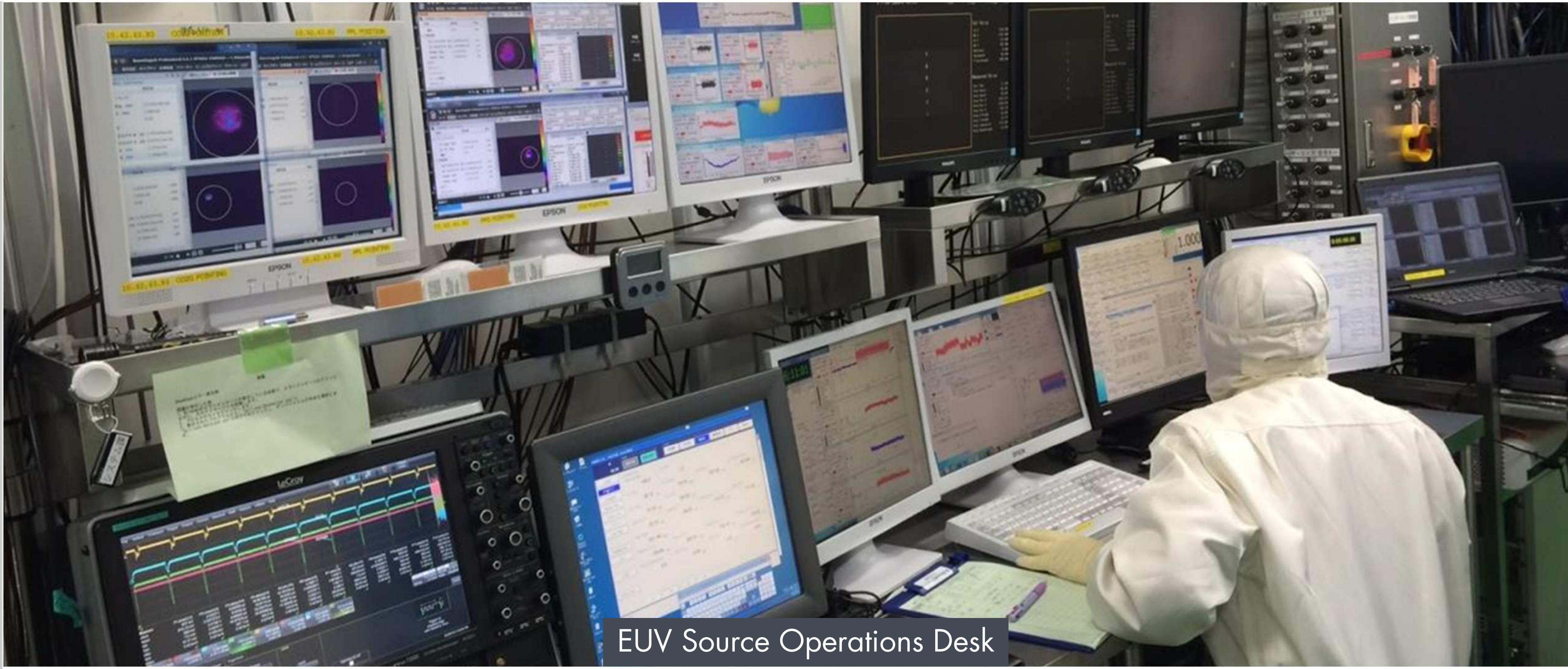
High speed droplet generator technology was successfully transferred from Prototype to the Pilot system

	Proto#1	Proto#2	Proto#2 ⇨ Pilot#1	
Droplet Speed (m/s)	45	60	90	90
Back Pressure (MPa)	12	20	40	40
Max Repetition Rate (kHz)	50	80	100	100



Droplet Status

Pilot#1 System in Operation



EUV Source Operations Desk

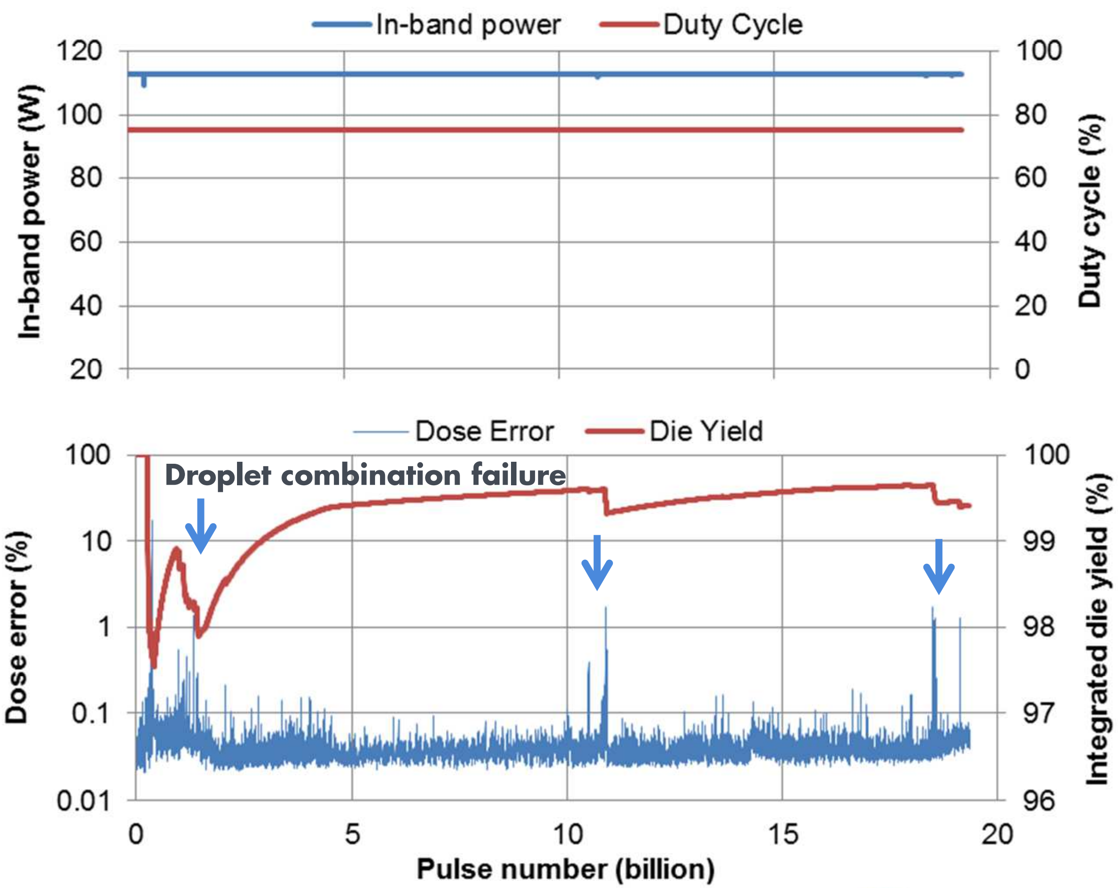
Dose stability performance (Apr.-17)

Burst pattern: 1000ms ON, 333ms OFF
Dose error: including pre-exposure phase(10ms)
Die yield: defined by 0.16% dose error

	Performance
Average power at IF	**85W**
Dose error (3 sigma)	**0.04%**
Die yield (< 0.16%)	**99.4%**
Operation time	**143h**
Pulse Number	**19Bpls**
Duty cycle	**75%**
In-band power	**113W**
Dose margin	35%
CE	4.4%
Availability 4wk	32%
Collector lifetime	-10%/Bpls
Repetition rate	50kHz
CO_2 power	12kW

Note

Dose error was mainly due to droplet combination failure and it was improved by droplet generator improvement(but not perfect).



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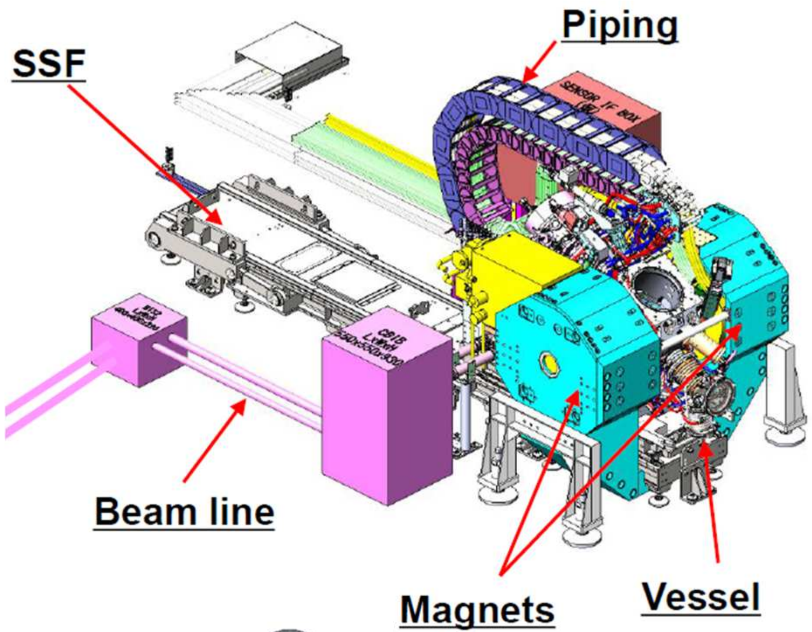
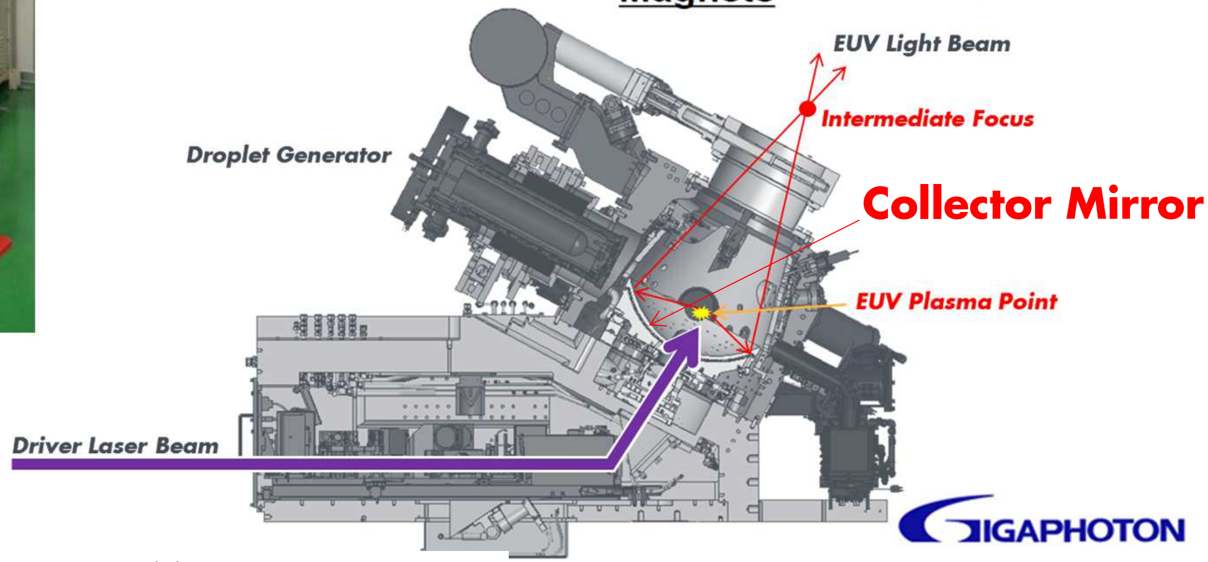
HVM READY LONG-LIFETIME COLLECTOR MIRROR

Pilot System EUV Chamber





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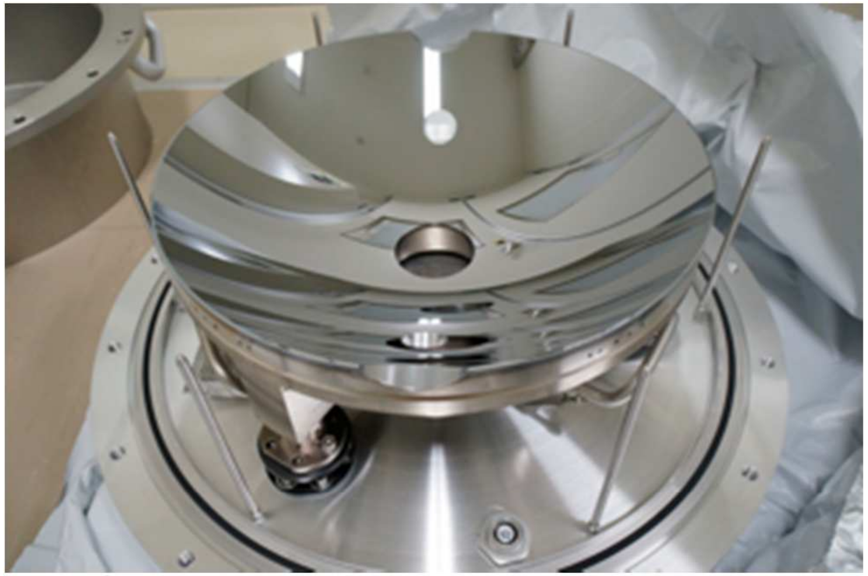
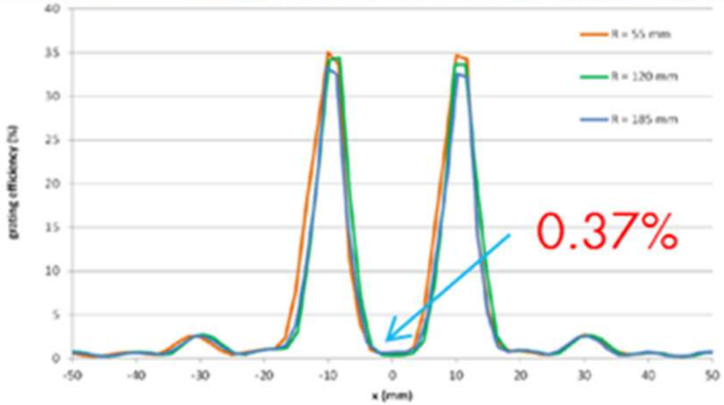
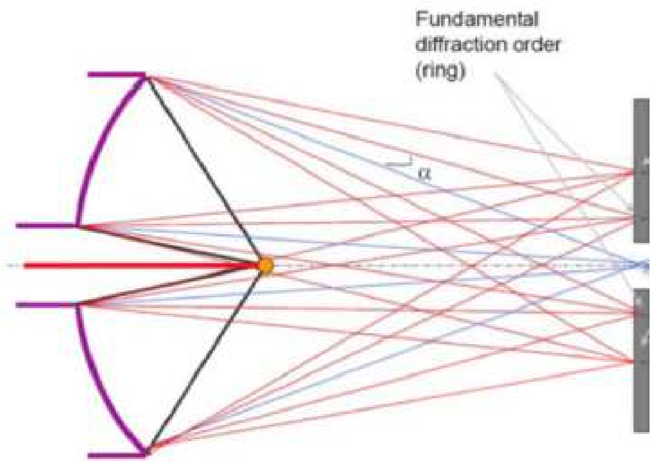
HVM Collector Mirror Specifications





- Size Φ412mm
- Weight 22kg
- Collector efficiency >74%
- Collector reflectivity >48%
- Grating structure



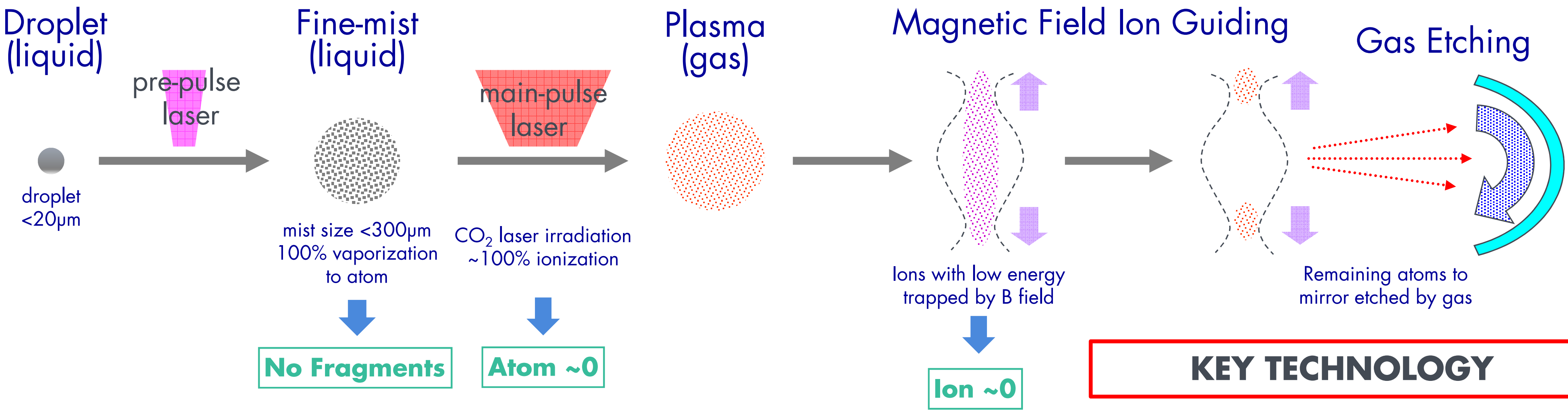
- Measured IR reflectivity: 0.37%

"SM3": Superconducting Magnet Mitigation Method

Gigaphoton's Magnetic Debris Mitigation concept

Higher CE and Power
- Optimum wavelength to transform droplets into fine mist
- Higher CE achievement with ideal expansion of the fine mist

Long Life Chamber
- Debris mitigation by magnetic field
- Ionized tin atoms are guided to tin catcher by magnetic field



KEY TECHNOLOGY

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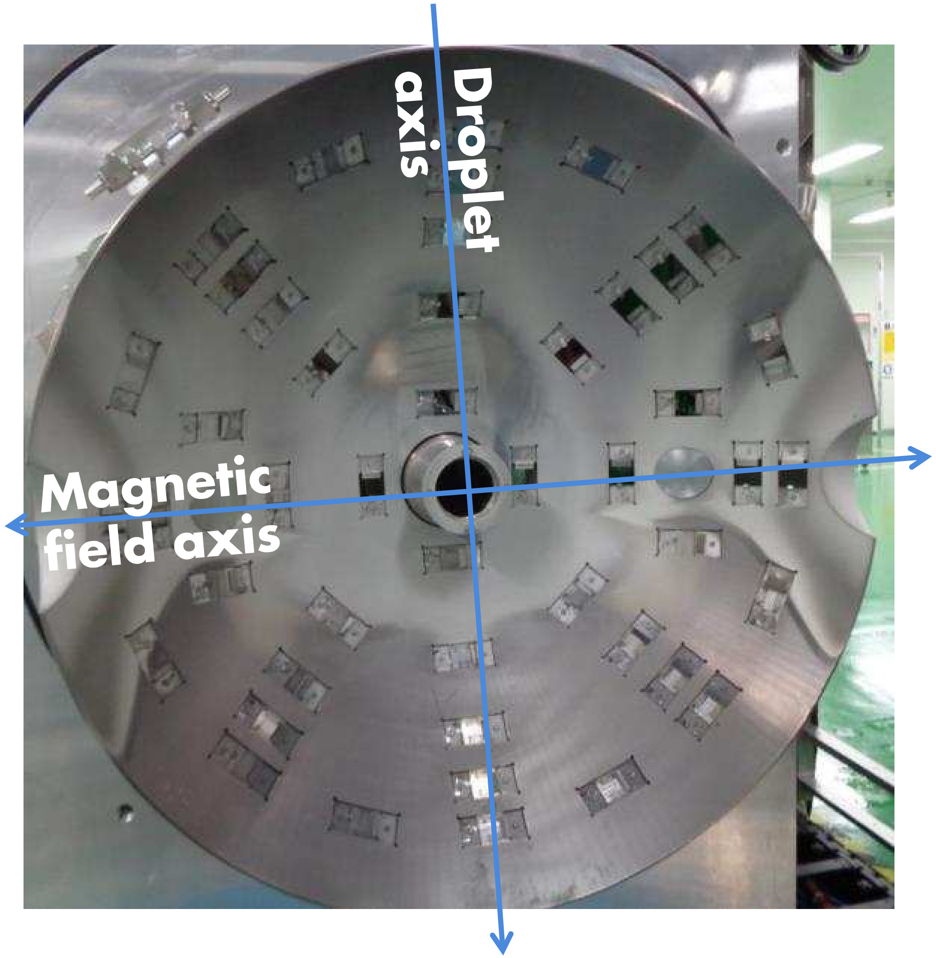
Debris Mitigation and Capping Layer Evaluations by Dummy Mirror



- Purpose
  - Evaluation of tin deposition distribution on the collector mirror
- Method
  - Dummy collector mirror (no coating)
  - Sampling plate (sample coupon)
    size: 15mmx15mmx0.7mmt
    material : Si plate (46 pieces)

    +multi layer (Si/Mo) + Capping layer
- Analysis after test
  - Surface condition : SEM
  - Deposited tin thickness : XRF
  - Capping layer thickness: TEM

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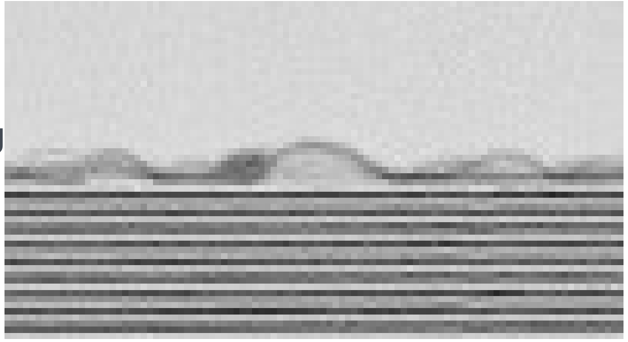
Difference of Deposition on the Sample Coupon of Dummy Mirror

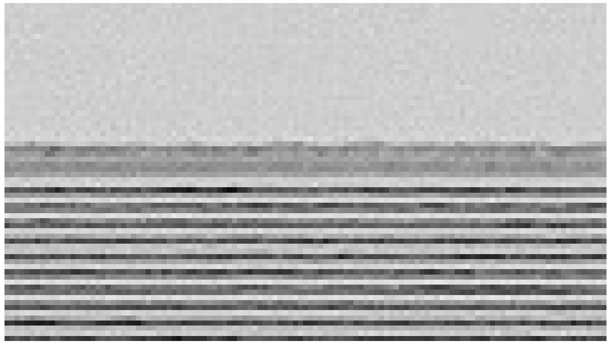
Capping layer disappearance Blister generation	Capping layer deformation Blister generation	Capping layer survived No blister generation

Capping

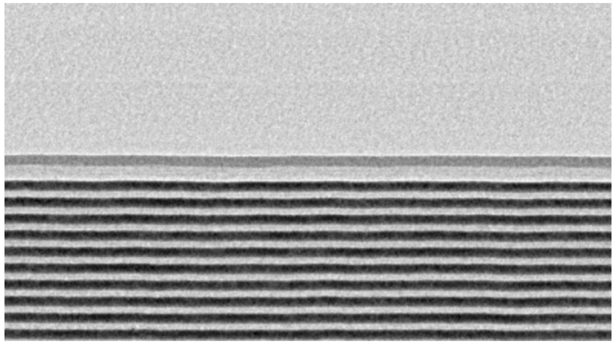
Mo/Si



A
124W, 7.3Bpls



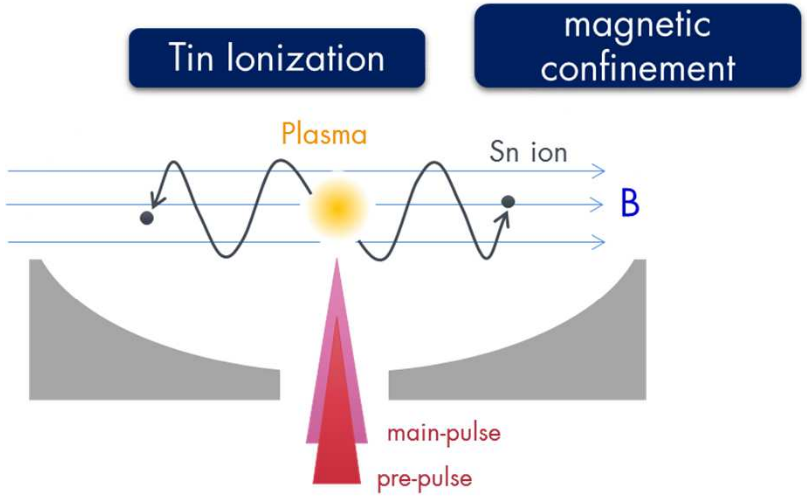
B
124W, 6.1Bpls



C
124W, 7.3Bpls

Etching and Dissociation of Sn on the Collector Mirror Surface

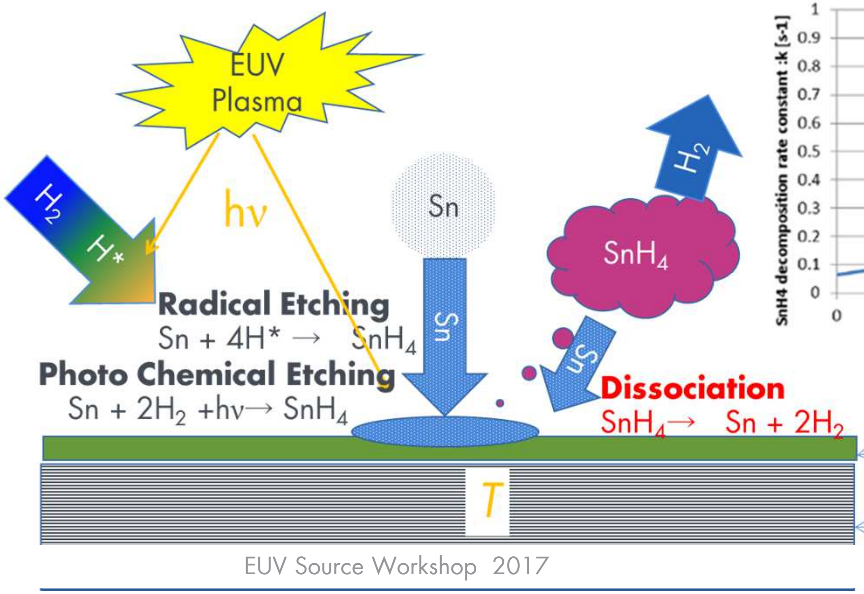
Chemical Equibrium on the Mirror Surface

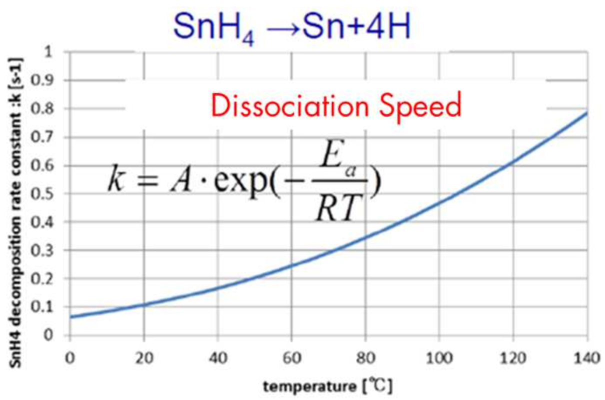


- Tin ionization & magnetic guiding
  - Tin is ionized effectively by double pulse irradiation
  - Tin ions are confined with magnetic field
  - Confined tin ions are guided and discharged from exhaust ports

- Protection & cleaning of collector with H_2 gas
  - High energy tin neutrals are decelerated by H_2 gas in order to prevent the sputtering of the coating of collector.
  - Deposited tin on the collector is etched by H radical gas*.
  - Gas flow and cooling systems for preventing decomposition of etched tin (SnH_4)

*H_2 molecules are dissociated to H radical by EUV-UV radiation from plasma.





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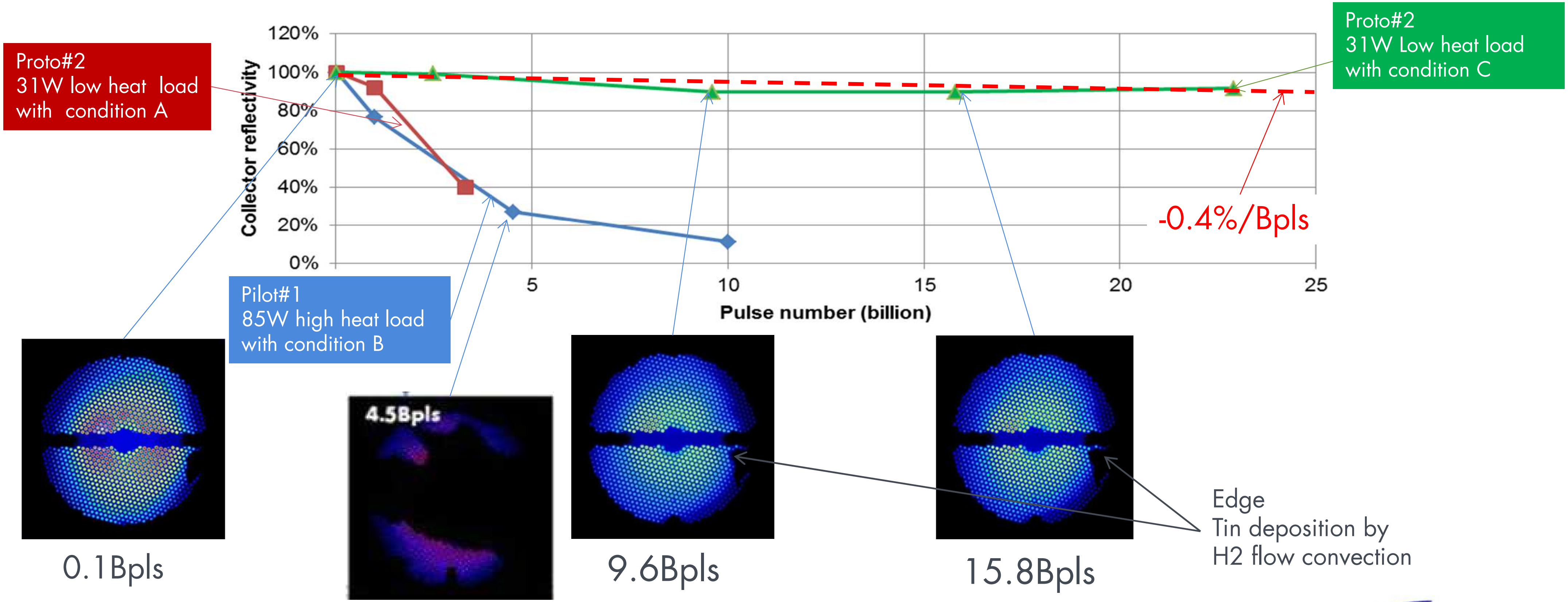
Collector lifetime status after improvement

- Power level of EUV: 100W in Burst, (= 2mJ x 50kHz), 33% duty cycle, 30W in average.
- Collector lifetime was improved to -0.4%/Bpls by magnetic debris mitigation technology optimization.



Far field pattern in test condition C

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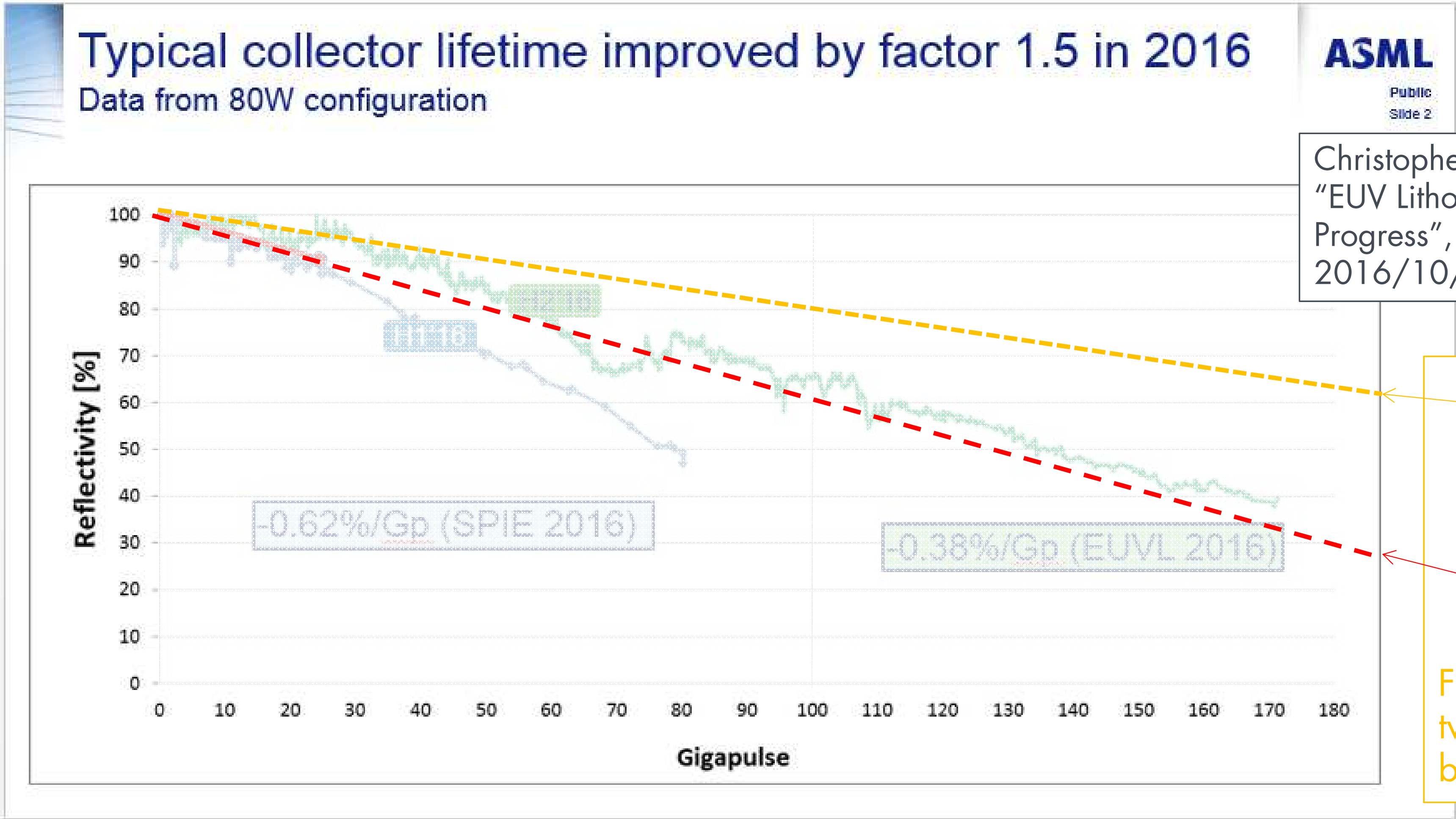
Mirror lifetime comparison between Another Source Data



Christophe Smeets (ASML)
"EUV Lithography Industrialization Progress", EUVL Symposium- 2016
2016/10/24-26 Hiroshima, Japan

GPI Target
-0.2%/Bpls

At present
-0.4%/Bpls

For comparison two lines are added by Gigaphoton

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Agenda

- Introduction
- HVM Ready System Performance Progress and Target
  - Power Scalability
  - Collector Mirror Life Extension
- Availability Improvement
- Summary

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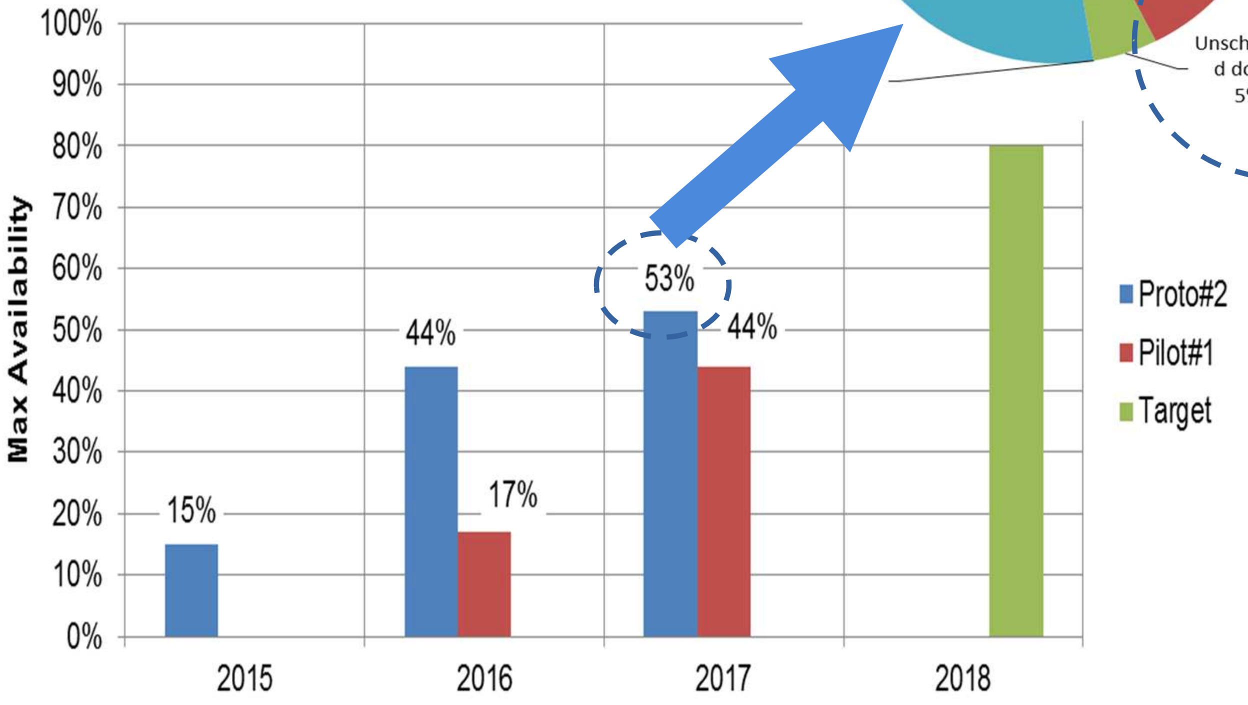
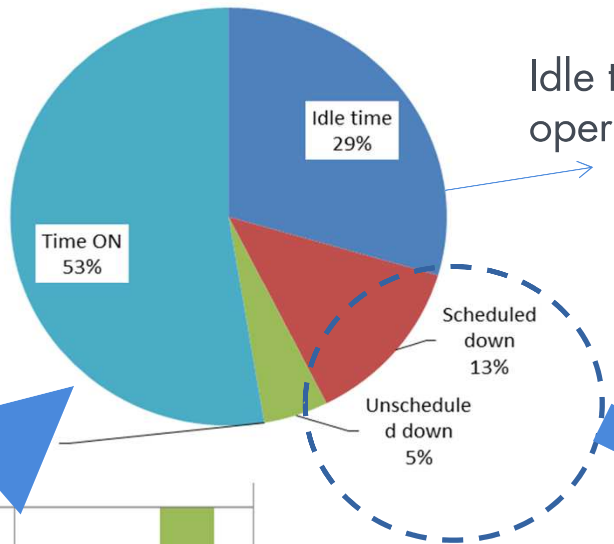
AVAILABILITY IMPROVEMENT TOWARD HVM

Availability Trends

- Availability improvement has been made and the challenges are classified by modules

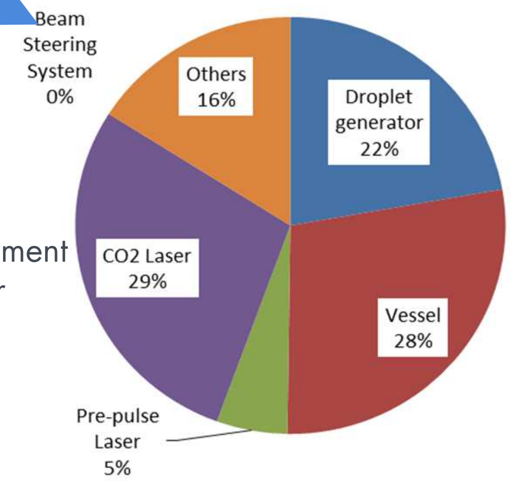


Availability breakdown



Idle time: Time for waiting operator or service

Downtime breakdown



Time for gas replacement in CO2 pre-amplifier

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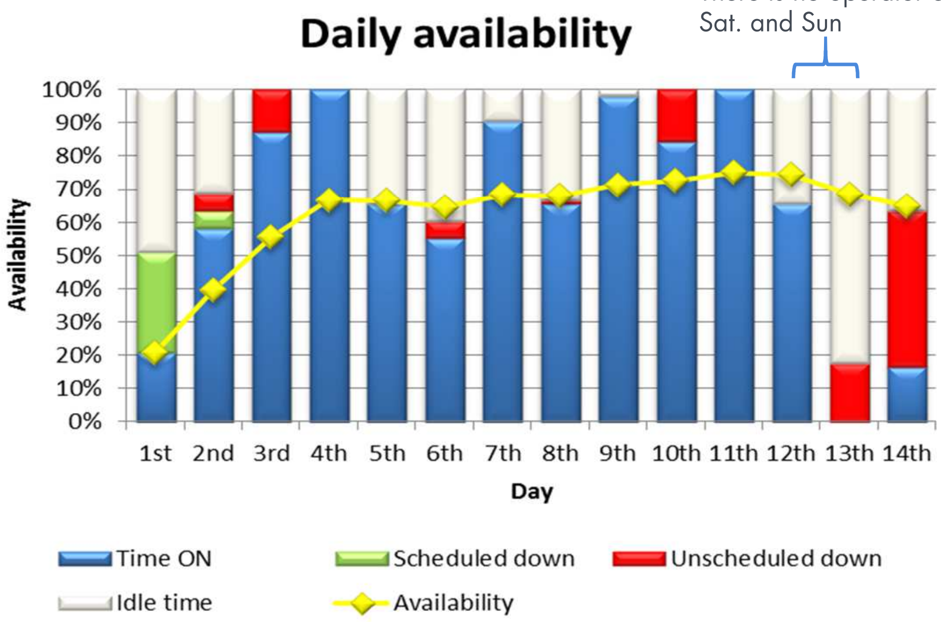
Availability potential test

- 2 week availability potential test was done. Availability was 64% and idle time was 25%. Availability is potentially achievable at 89%.

There is no operator on Sat. and Sun



Dose error : System stopped at > 2% Dose error (3 sigma) /10kpls slit and error was not recovered by automatic function
Idle time: Time for waiting operator.

24 hour x 7 days definition
Unmanned operation between 9pm thru 8am

System stop event table

MTTR: 2.8h

Day	Event	Repair time	Root cause	Countermeasure
2	Dose Error	1.25h	25% dose margin is not sufficient	Dose margin 25% -> 28% New shooting control will be applied at Jun.
3	Sensor Error	3h	Sensor reliability	New sensor will be applied (TBD).
5	Dose Error	-	Droplet combination failure	Countermeasures will be applied at Jul.
6	Dose Error	1.25h	Shooting control algorism	Same as Day 2 countermeasure
8	Dose Error	0.25h	28% dose margin is not sufficient	Dose margin 28->35% . Same as Day 2 countermeasure.
10	Dose Error	3.75h	Droplet position instability due to particle issues.	Countermeasures are going on.
13	Dose Error	4.25h	Mirror damage in BTS(Beam transfer system) for new mirror evaluation.	Replacement to conventional mirror
14	Dose Error	11.25h		

Improvement plan >80% availability

		Current	Dec-17	2018
Availability	Demonstrated	**64%**	N/A	N/A
	Calculated or Target	**(89%)** +Idol	**>80%**	**>90%** Target
Vessel including Collector	Lifetime	3.0 months	**6 months**	**6 months**
Droplet generator	Lifetime	0.5 months	<-	**2 months**
	Maintenance time	24 hour	<-	**16 hours**
CO2 Lase chamber	Lifetime	24 months	<-	<-
	Maintenance time	36 hours	<-	<-

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SUMMARY

Summary

- **Pilot#1 is up running and its demonstrates HVM capability;**
  - *High conversion efficiency 5% is realized*
  - *Demonstrated EUV power at113W In-burst power at 75% duty (85W average) for 143hours operation.*
- **Full scale of Collector Mirror integration test is in progress;**
  - ***S**uperconducting **M**agnet **M**itigation **M**ethod **"SM3"** realized very low degradation at 0.4%/Gp of reflectance above 100W level operation (up to 23Gp).*
- **Pilot#1 shows HVM Ready potential;**
  - *Pilot#1 system achieved potential of 89% Availability (2weeks average).*

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